FROM PERSPECTIVE RESTITUTION TO MIXED REALITY RECONSTRUCTION OF SAN NICOLÒ DEI CARMELITANI CHURCH IN PALERMO

F. Agnello[1], L. Barrale[1], V. Garofalo[1], S. Morena[1]*

[1]University of Palermo, Department of Architecture, Palermo, Italia – (fabrizio.agnello, laura.barrale, vincenza.garofalo, sara.morena)@unipa.it

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ABSTRACT:

Digital surveying and representation tools are widely used for the virtual reconstruction of historic buildings that have vanished or have been transformed. When changes or destructions occurred after the first half of the XIX century, the reconstruction process can be based on photographic images, if available. Photos provide an effective support for the reconstruction of lost buildings, especially when drawings or previous surveys are not available.

The 3D reconstruction from archive images has become a relevant topic in almost recent years. In 2013 Migliari et al. proposed a method that allows the reconstruction of 3D models from a single image using perspective restitution. In those years computer engineers developed digital tools that supported inner and outer orientation of archive images. In the years from 2017 to 2019 several studies focused on the reconstruction of lost buildings with photogrammetric traditional and SfM techniques.

In this study an un-assisted process is proposed for the reconstruction of a lost buildings from a single image: perspective restitution developed with digital representation tools allowed the retrieval of inner and outer orientation of archive photos and the reconstruction of the case study, a church that no longer exist. Outer orientation and scaling were provided by the lidar survey of those buildings that are still in place. Finally, a motion tracking commercial software has been tested for the contextualization of the 3D reconstruction model.

1. 3D RECONSTRUCTION FROM ARCHIVE PHOTOS

Since the very beginning of photography, monuments and historic towns where shot to illustrate the beauty and richness of cultural heritage in Europe and around the world.

The technique of photography, literally ‘writing with light’, was set up almost contemporarily in France and England in the first half of the XIX century. Few years later, in the second half of the century, Aimée Laussedat in France and Albrecht Meydenbauer in Germany foresaw that photography could be used to survey buildings, towns and the surface of the earth.

Both Laussedat and Meydenbauer used two different techniques to extract features and dimensions from photos: a) perspective restitution from a single image; b) intersection of rays with the aid of a couple of photos of the same subject, taken from different points of view.

The first technique was no more than the application to photos of the inverse path of perspective, that had been illustrated since 1600, in one chapter of the treatise on perspective of Guidobaldo del Monte.

The second technique used the optical principle of the plane table, a mechanical device used for the survey of the territory at least since the XVI century.

Laussedat observed that, at his time, lenses produced images that were strongly affected by distortions and that perspective drawings, produced with an optical device named *camera lucida*, matched the projective features of linear perspective more than photos could do. Meydenbauer, on the contrary, preferred trying to improve the geometric quality of photos and started manufacturing his own cameras.

The surveying technique that used photos was called *Métrophotographie* by Laussedat and *Photogrammetry* by Meydenbauer; no need to say which term succeeded.

Laussedat published the book *Metrophotographie* in 1899; few years later, in 1912, Meydenbauer published his *Handbuch der Messbild Kunst in Anwendung auf Baudenkmäler und Reiseaufnahmen* (Handbook of the art of measuring images in application to monuments and travel recordings).

The images that illustrate the two books clearly show that the authors used both the ‘monocular’ perspective restitution and the ‘stereoscopic’ intersection of rays.

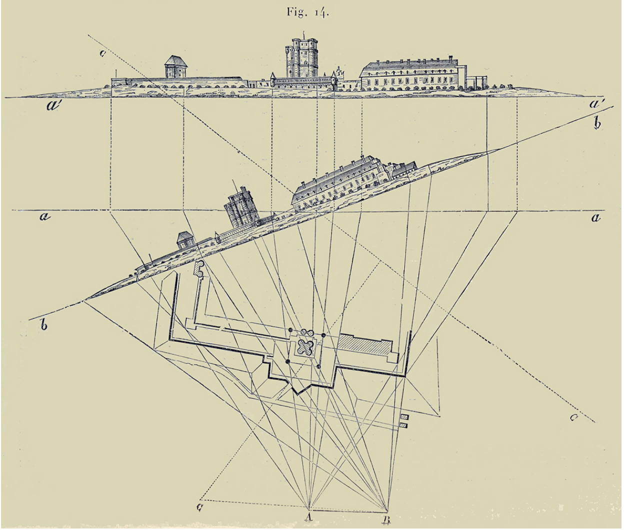

Figure 1. A. Laussedat, Reconstruction from two perspective drawings made with the ‘camera lucida’ of the plan of the fortification of Vincennes (Laussedat, 1899, p. 28).

* Corresponding author

The restitution of the plan of the Chateau de Vincennes was developed by Laussedat with the aid of two perspective drawings of the building, taken with a *camera lucida* from two points of view: the points of the plan were detected at the intersection of projective rays, given the position of the station points and the orientation of the camera lucida (fig. 1). In the same book a monocular approach that uses perspective restitution is proposed for the reconstruction of plans and front from of Santa Maria delle Grazie church in Milan from one photo (fig. 2).

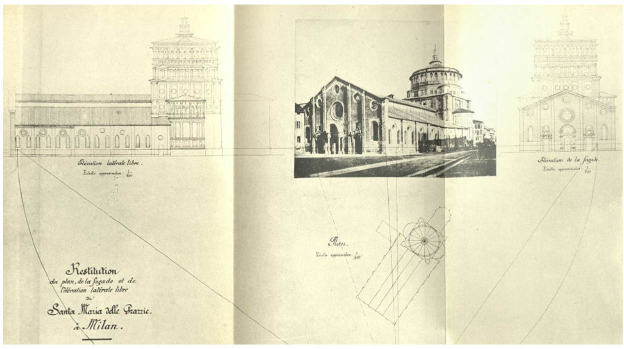

Figure 2. A. Laussedat, Reconstruction from a photo of the plan and fronts of Santa Maria delle Grazie church in Milan (Laussedat, 1899, planche 1).

The restitution developed by Laussedat shows that the principal point of the image is not located at the center of the image; this happens when the lens is moved and its optical axe does not intersect the center of the plate that records the image; the cameras built by Meydenbauer allowed to shift the lens in a vertical direction, to reduce the convergence of vertical lines of buildings; this solution implied the shift of the principal point upwards or downwards along the vertical axe of symmetry of the image.

Meydenbauer was the first to realize the potential of photography for the documentation of monuments, especially when wars or natural disasters would cause damages or destructions; in 1860 he wrote a memorandum to ask the curator of cultural heritage in Prussia to set an archive of photos of monuments.

In the XX century stereoscopic photogrammetry became the only photogrammetric technique used for surveying, whereas perspective restitution was progressively dismissed.

Nonetheless, in 1930, the French architect Henri Deneux published a book titled *Metrophotographie*, a tribute to Laussedat, with an in-depth discussion on monocular perspective restitution, developed through the illustration of many case studies. The work of Deneux is still today a reference for scholars and technicians aiming at monocular reconstruction with the aid of perspective restitution.

As mentioned above, the work of Deneux was almost ignored, due to the inaccuracy of perspective restitution developed with photographic prints and traditional drawing tools, e.g pens, pencils, rulers and the like.

The only study, as far as the author knows, published after the book of Deneux and before the introduction of digital drawing tools, was written in 1964 by Mario Docci, teacher at La Sapienza University in Rome (Docci, 1964).

The book provides a detailed description of the peculiar features and differences between monocular and stereoscopic restitution, highlighting the strengths and weaknesses of both techniques. The author considers perspective restitution an application of ‘basic’ inaccurate photogrammetry, useful only for educational purposes, not comparable to stereoscopic ‘classical’ accurate photogrammetry.

At the end of the past millennium, the development and diffusion of personal computers led to the development of two different solutions for monocular restitution from photos: a) rectified images; b) assisted 3D reconstruction of simple volumes.

The first solution, based on the principles of projective correspondences between planes, allows the transformation of the perspective image of a flat surface into its parallel orthogonal projection, by means of the position of four or more points. Different tools for rectification, such as commercial *Rollei MSR* or freeware *RDF*, developed by IUAV, were released.

The second solution for monocular ‘digital’ restitution was developed, almost at the same time, by many researchers (1); here, only the works of Paul Debevec and Frank A. Van den Heuel will be shortly mentioned.

In 1998 Van den Heuel, researcher in Geodesy and Photogrammetry at the Delft University proposed a tool that assisted the calculation of intrinsic and extrinsic orientation (2) of a single image via the identification of lines linked by geometric constraints, such as perpendicularity or parallelism; one known distance between a couple of points allowed to scale the photogrammetric model. The tool developed by Van den Heuel was not released at that time, nor in the years that followed.

In the same decade Paul Debevec, today Director of Production and Innovation Research in Netflix, delivered his PhD thesis titled *Modeling and Rendering Architecture from Photographs: a hybrid geometry and image-based approach*. Based on this research, the software *Façade* has been implemented as a tool for the extraction of quick 3D models to be used by entertainment companies; the workflow of *Façade* is almost similar to the software tool developed by Van den Heuel; the software allowed the extraction of 3D models from a single image via the detection of lines, surfaces and solids that would fit the real geometries depicted in the image. *Façade* has never been released, but inspired the development of the software *Canoma* by Robert Seidl e Tilman Reinhardtand and of the software *ImageModeler*, released in 1998 by RealViz.

ImageModeler has largely been used in the following decade; in 2008 the software was purchased by Autodesk and a new ‘2009’ update was released; after that, the software has not been updated nor it appears in the gallery of Autodesk products.

The legacy of monocular assisted restitution and reconstruction is today received by *Fspy* and *Sketchup*; the first one is a freeware tool that allows the calculation of inner and outer orientation via the identification of orthogonal lines; the second one is a commercial product that works in a similar way. *Sketchup* includes a set of tools that can be used to model the scene from the point of view of the image; *Fspy* includes only basic modeling tools, but the perspective model can be easily linked to *Blender*, where the reconstruction process can be developed with the aid of powerful tools. If the vanishing points of three mutually orthogonal directions are known, *Fspy* allows to calculate the position of principal points, even when it is not at the center of the image.

Until 2013 digital representation and modeling tools had not been used to solve intrinsic and extrinsic orientation of images and test if perspective restitution, effectively illustrated by Deneux and Docci, could be revived by digital drawing tools.

(1) For a detailed and comprehensive description of image-based modelling techniques, see El-Hakim et al., 2002 and Remondino et al., 2006.

(2) Intrinsic orientation refers to the calculation of the position of principal point and of the focal length; extrinsic orientation is the calculation of the pose of the camera, i.e. the position of the point of view in a given environment and of the orientation of the shooting axe.

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In that year Riccardo Migliari, Marta Salvatore and Federico Fallavolita, researchers at La Sapienza University in Rome, published a study (Fallavolita et al., 2013) that used modeling tools to calculate intrinsic and extrinsic orientation of an archive photo of a village. This study clearly showed, even in the restricted editorial layout of the review, that digital tools could overcome many limitations that had led to dismiss perspective restitution in the pre-digital era. Digital tools allowed a closer inspection of the photo, the representation of the furthest vanishing point and the 3D reconstruct of the volumes depicted in the image, an impossible task when operating with traditional drawing tools, using the revolution of flat figures onto the picture plane.
The study of Migliari et al. unchained perspective restitution from the semi-automatic workflows of software tools, and enlightened the potentials offered by the application of ‘new’ digital representation tools to ‘old’ perspective restitution.
This study encouraged the use of digital representation and modeling tools for the reconstruction of lost buildings from archive images and revived perspective restitution as an effective tool for the calculation of intrinsic and extrinsic orientation of photos. The path traced by the authors was followed by many others.
When perspective restitution addresses the reconstruction of a destroyed building from archive photos, two different circumstances can occur: the photo shows a scene that has disappeared; b) the photo shows a destroyed buildings together with extant buildings; c) a fragment of the destroyed building has escaped destruction and can be surveyed.
In the first circumstance intrinsic orientation can be extracted only if one or two angles formed by horizontal lines and the vanishing point of vertical lines are known (3); extrinsic orientation can be retrieved if a distance between two points lying on a oriented line is known. When no past survey of the vanished scene is available, a historic map of the site can support both intrinsic and extrinsic orientation. If a fragment of the building has survived and can be surveyed, it can be placed in the reconstruction model to validate the accuracy of the restitution layout.
When the photo shows extant and destroyed buildings at once, the orientation can be calculated both with perspective restitution and with semi-automatic approaches that calculate space resection with SfM or other digital photogrammetric tools.
In the study of Migliari et al. the survey of extant buildings is used to retrieve the extrinsic orientation of the image by means of a 3D application of the Snellius Pothenot theorem; if the resulting position of the point of view would appear incompatible with the photographic technique or with the morphology of the site, then the restitution layout should be reconsidered.
When using photogrammetric tools, two approaches have been used: the first one is based on the interactive identification of homologous points, lines or surfaces on two or more images, to calculate the intrinsic orientation of the image; if some of these points are surveyed, than extrinsic orientation is calculated. This approach can be performed with the photogrammetric software Photomodeler (Bitelli et al, 2017, Zawieska, 2017).
The second one uses SfM automated techniques to calculate both intrinsic and extrinsic orientation (De Luca, 2010, Bevilacqua, 2019). Interactive tools are to be preferred when the subject of restitution is well depicted in the image and supports the identification of parallel/orthogonal/vertical lines. In photos of urban historic sites, taken from the air or from a relevant distance, a building usually appears in a small part of the image and the surrounding buildings feature ever changing orientations; in these occurrences, automated SfM photogrammetric approaches can result more effective than perspective restitution or interactive workflows.

(3) The range of possibilities is much wider than this; further approaches are reported in Deneux (Deneux, 1930) and Docci (Docci, 1964).

2. THE CASE STUDY

The San Nicolò dei Carmelitani church was located in *Piazza Bologni* (formerly *Aragona*), a wide rectangular square opening onto the *Cassaro*, the main east-west axe of the historic town of Palermo, not far from the monumental crossroads named *Quattro Canti*. The square was opened in 1567 in the context of an urban renewal campaign promoted by Carlo d’Aragona. The rectification of the *Cassaro* and the opening of the square caused the demolition of a former San Nicolò church; the new church, commissioned by the Bologna family was built in 1568 (Lo Piccolo, 2009).
In 1579 the church was bestowed to the Carmelitani religious order by Francesco Bologna. The construction of the church had a long duration: in 1625 four chapels were built, but the stucco decorations inside the church were completed only in 1670. The church had three naves, divided by four arches and three columns per side; four chapels opened on each aisle. The inner layout was echoed by the façade in stone, divided into three vertical strips with the main entrance flanked by two minor doors.
In 1632 the bronze statue portraying the Spanish King Carlo V was placed upon a marble pedestal at the northern end of the square, close to the *Cassaro*. During the fascist regime (1922-1942) the statue was moved at the opposite end of the square, to facilitate the celebrations of the dictatorial rituals. During WW2 the statue was removed from the square, to prevent the risk of destruction; at the end of the war the statue was rearranged in its original spot; it is not clear if this placement was accurate or not. If so, the statue that appears in historic photos would not match the present position of the statue.
The church was deeply modified over time; in 1875 it was transformed into a post office and its façade was dramatically reshaped; on the contrary. the facades of the buildings close to the church kept their original layout.

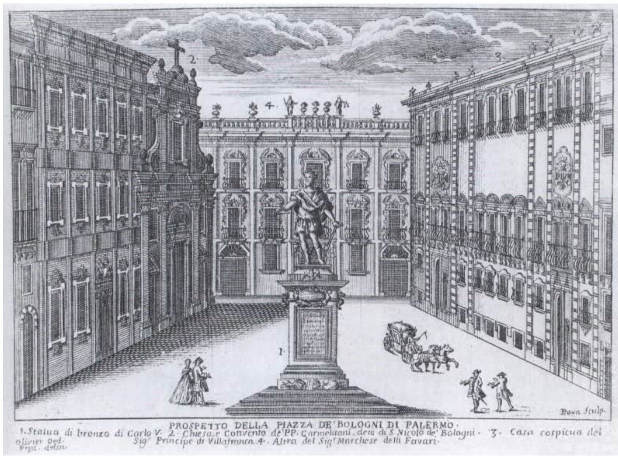

Figure 3. A. Bova, *Prospetto della piazza de’ Bologni di Palermo*, 1761.

The images that illustrate the façade of the church are: a) an engraving made by Bova, dated in the 18th century; b) two stereoscopic photos taken by the French photographer Eugene Sevaistre in the years around 1860.
In the engraving made by Bova (fig. 3) the square is a ‘perfect’ rectangle and the statue is magnified; though foreshortened by perspective, the façade of the church is properly represented.

The stereoscopic photos of Sevaistre are taken from the north western corner of the square; the photos show the facades of the noble palaces, that surrounded the church and delimited the eastern and southern edge of the square; these buildings are still in place and have almost kept, save minor modifications, the layout documented by the photos (fig. 4).
A minor discrepancy appears in the image of the upper part of the façade of the church; the photo shows three small arches where the bells were probably placed, whereas the drawing by Bova displays a huge cross.

Figure 4. E. Sevaistre, *Palermo – Piazza Bologni*, ca. 1860 (Civico Archivio Fotografico, fondo Lamberto Vitali).

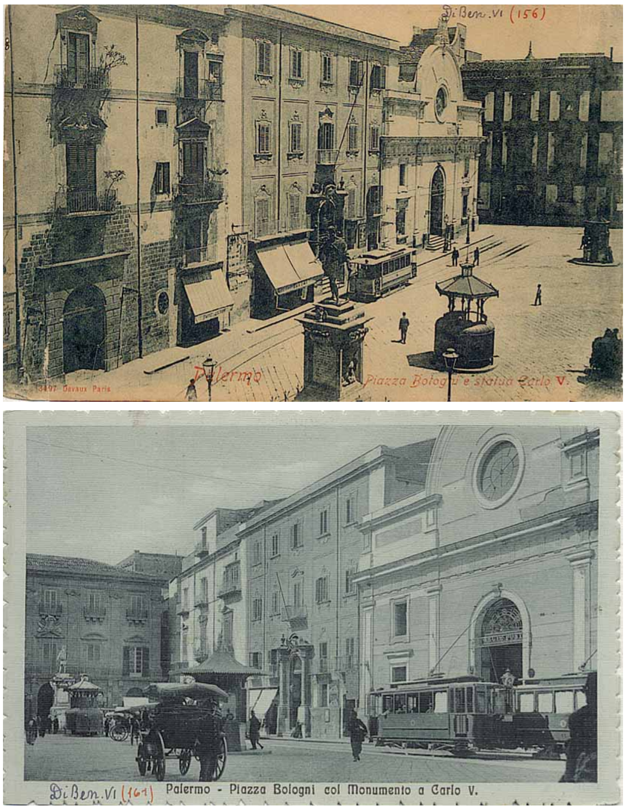

Figure 5. *Piazza Bologni,* postcards (Municipal Library of Palermo, Di Benedetto Archive, Lic. CC BY SA 4.0).

The façade of the post office is documented by two postcards from the Di Benedetto Collection, stored at the Municipal Library of Palermo (fig. 5).
The lower part of this façade kept the division in three bays, but the openings appear dramatically reshaped; the upper part has been redesigned: a semicircular arch with a circular giant clock substituted the higher part of the previous façade and the tympanum at its upper end.
In 1943 the south eastern corner of Piazza Bologni was hit by bombs and the post office was destroyed. The building that took the place of the destroyed post office was built in the ‘60s and is today used by the University of Palermo.

3. DATA ACQUISITION

When the reconstruction process is developed with archive photos that portray vanished and extant buildings at once, the survey of the site provides an effective support for the calculation of the extrinsic orientation of archive images.
Piazza Bologni has been surveyed with laser scanning techniques; six scans, almost placed along the south-north axe of the square, have been recorded with a Leica HDS 7000 phase-based laser scanner. Scans have been registered with the Autodesk software Recap and the redundancies in the registered point cloud have been removed through a sampling operation executed with the free software CloudCompare.
The point cloud has been uploaded in a Rhinoceros, the representation and modeling software used in this research, and the angle formed by *x* axis and the horizontal section of the façade of the university building has been measured.
This value was used to rotate the sampled scans with CloudCompare, so that the façade of the university building has become parallel to *xz* reference plane. Even the scans in the Recap project have been rotated; this rotation would appear redundant, but it has been performed with the aim to extract the coordinates of specific points of the cloud from the spherical views of the scans, that allow an easier and more precise detection and annotation of points to be used for the orientation of the SfM photogrammetric model (fig. 6).

Figure 6. Extraction of points’ coordinates from the spherical view in Recap.

The photos of the square, shot with a Sony Alpha 7RIII full-frame mirrorless camera with a resolution of 36Mpx, have been aligned in the SfM software Agisoft Metashape.
The extrinsic orientation of the photogrammetric model has been calculated with the reference tools of the software, using 19 markers. The coordinates of the markers, taken from the laser scanning point cloud, allowed the calculation of the mean error, that resulted equal to 2.5cm, a value that is acceptable for the purposes of this research.
The following step of the SfM processing addressed the automated calculation of the intrinsic and extrinsic orientation of

the image shot by Sevaistre, which will be used for the reconstruction of the façade of San Nicolò church.
The use of SfM tools for the orientation of archive images has been successfully tested in previous studies (De Luca, 2010 and Bevilacqua, 2019). However, in this case, automatic alignment has not succeeded, probably due to the radiometric differences between the archive images and the photos taken for this study. After 11 of the 19 markers were placed on the photo of Sevaistre (fig. 7), the software could compute both intrinsic and extrinsic orientation, assuming that the principal point of the image corresponded to the center of the image (fig. 8).

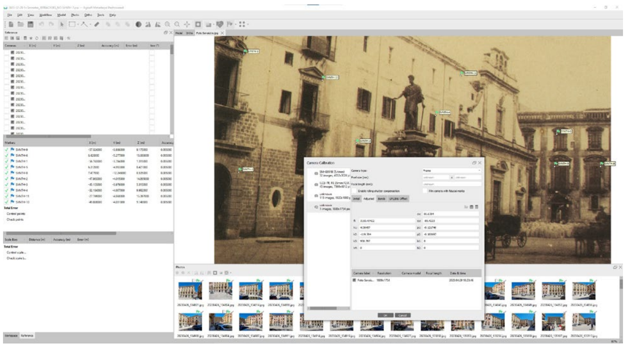

Figure 7. SfM orientation of the archive image.

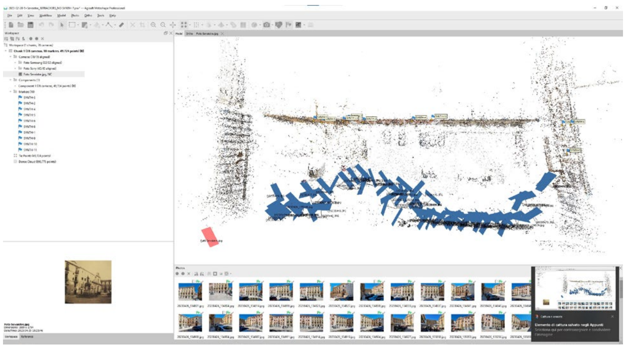

Figure 8. Photogrammetric SfM model; the image of Sevaistre is highlighted in red.

The orientation of the archive image in the photogrammetric model, and the correspondence between image and real present features has been visually validated by the view of the image and the point cloud from the center of projection *V* (fig. 9).
The model of the camera has finally been exported with the omega-phi-kappa format and the position of the center of projection *V* and the orientation of the shooting axe have been reconstructed in Rhinoceros.
In this research, further experiments addressed the possibility to retrieve the orientation of a single archive image; it has been tested that Metashape demands at least three aligned images to perform the calculation of the archive photo.
Other attempts focused on the automated orientation of the image with the aid of the motion-tracking commercial software Syntheyes, that will be illustrated in the fifth paragraph. When the coordinates of 11 points of the image are available, Syntheyes does not need further aligned images to perform the calculation of the orientation of the archive image, but it should be noted the results produced by Metashape appear more accurate. The final step of the acquisition process addressed the capture of a footage to be used for the experiments on motion tracking, with a smartphone stabilized with the aid of a hand-held DJI gimbal.

Figure 9. Photogrammetric SfM model referred to the laser scanning reference coordinate system.

4. THE RECONSTRUCTION PROCESS

The reconstruction process has been developed with the aid of the archive images that document the façade of the church and of the post office.
The main problem that the restitution of the orientation of archive photos of Piazza Bologni has to face is related to the presence of multiple directions and to the difficulty in detecting horizontal reference planes; these problems are quite usual when dealing with archive photos of historic sites.
The facades of the buildings along the edges of the square are not parallel nor orthogonal to each other. Furthermore, the survey of the square has shown that the angles formed by two attached facades are almost similar to a flat angle; this geometrical condition is not easily detectable in the perspective image, since the vanishing points of the two facades result close to each other; for this reason, the use of known angles for the detection of intrinsic orientation resulted quite difficult.
Another critical feature in photos of urban historical contexts is that parallel lines are usually visible in small areas of the photo and thus the identification of their vanishing points is almost difficult.
This is why the calculation of the intrinsic orientation of the photo of Sevaistre has been performed with two different approaches: perspective restitution and photogrammetric SfM processing (see previous paragraph).
Perspective restitution is no more than the inverse path of perspective and is rooted in the principles of descriptive geometry.

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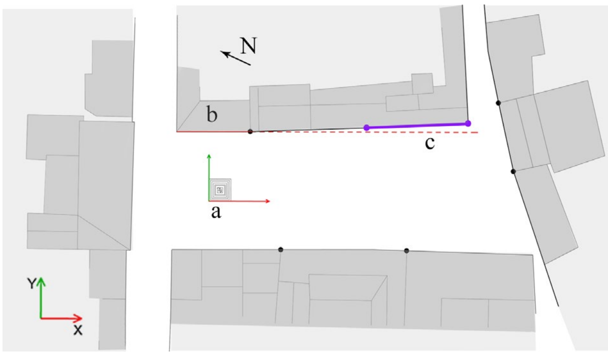

Figure 10. Plan of Piazza Bologni and orientation of the reference coordinate system.

A relevant datum that results from the laser scanning survey of the square is the parallelism between the façade of the palace that appears in foreground and two fronts of the marble pedestal of the statue of Carlo V (fig. 10).
The photo of Sevaistre shows vertical lines that converge to a vanishing point. This evidence suggests that Sevaistre used standard cameras that did not allow relative movements of the lens and the flat surface holding the plate that records the image. The cameras that allow to move the lens, named *view* cameras, were largely used, in the past century, to shoot monuments, because they allowed to mitigate the convergence of vertical lines. It must be taken into account that, at the time when Sevaistre shot his photos in Palermo, the photographic technique was at its beginnings and that the experiments of Meydenbauer for the construction of *view* cameras are dated 1875.
It is well known that in standard photos, save geometric distortions, the principal point *P* is placed at the center of the image and that the center of projection *V* lies on the line through *P* that intersects the image at straight angle, named *principal line*; the segment *VP* measures the *principal* distance. When working with archive images taken from books or from the internet, the probability that the image has been cut must be taken into account.
The image of Sevaistre has been retrieved in its full format and thus the position of *P* can be fixed at the intersection of the diagonals of the image frame.
The reconstruction of the intrinsic orientation of the image of Sevaistre with perspective restitution was developed as follows: a) two vanishing points of horizontal lines at straight angles, *Fx’* and *Fy’*, are detected; b) the vanishing line *fxy’* through these points (horizon line) is drawn; c) the vanishing point of vertical lines *Fz’* is detected and the line orthogonal to *fxy’* is drawn; d) the image is rotated on its plane to make the *fxy’* horizontal.
Since *Fz’* is not a point at infinity, *fxy’* does not go through *P*.
The projection center *V*, that corresponds to the nodal point of the lens, can be retrieved at the intersection of 3 spheres whose diameters correspond to the segments *Fx’Fy’*, *Fx’Fz’* and *Fy’Fz’* (Grammatikopoulos, 2004). Actually, when *P* is known, *V* can be retrieved at the intersection of the *principal line* and one of the three spheres (fig. 11).
As a prerequisite for the calculation of the extrinsic orientation, the perspective model has been rotated twice: the first rotation, around the line *fxy’*, makes the line from *V* to *Fz’* parallel to *z* axis in the digital scene; the second rotation, on the *xy* plane, makes the line from *V* to *Fx’* parallel to *x* axis.
The extrinsic orientation of the image has been retrieved with the aid of a segment of a line having the *x* direction, corresponding to the distance between two openings at the first floor of the foreground façade, measured on the laser scanning point cloud. An equal segment has been measured on the line from *V* to *Fx’* and the so-called *parallelogram rule* has been used to detect the spatial position of the segment in the 3D perspective model. The whole perspective model has finally been moved to superimpose the calculated segment to the real one. The position of the camera and the orientation of the shooting axe are thus referred to the real scene. The position of *V* resulted compatible with the real environment and its height from the ground, equal to 1.30m, can be considered acceptable.

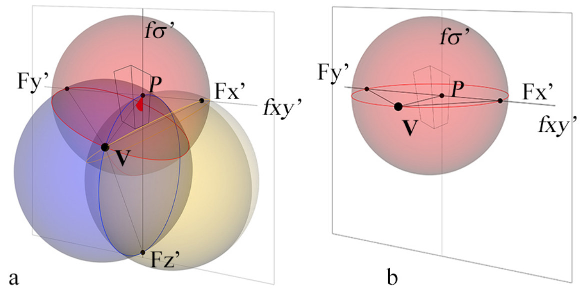

Figure 11. The three spheres solution and the simplified solution when P is known.

Before starting the reconstruction process of the façade of the San Nicolò church, a comparison between the outputs of perspective and SfM orientation has been performed. The coordinates of *V* calculated with perspective restitution and SfM tools revealed differences that range from 2 and 10cm, whereas the orientation of the shooting axe has resulted almost unchanged.
The reconstruction of the façade of the church (1575-1875) was carried out as follows: a) the vanishing point *Fc’* of horizontal lines of the façade has been detected on the *fxy’*; b) the line through *V* and *Fc’* has resulted almost parallel to the horizontal section of the university building (fig. 12).

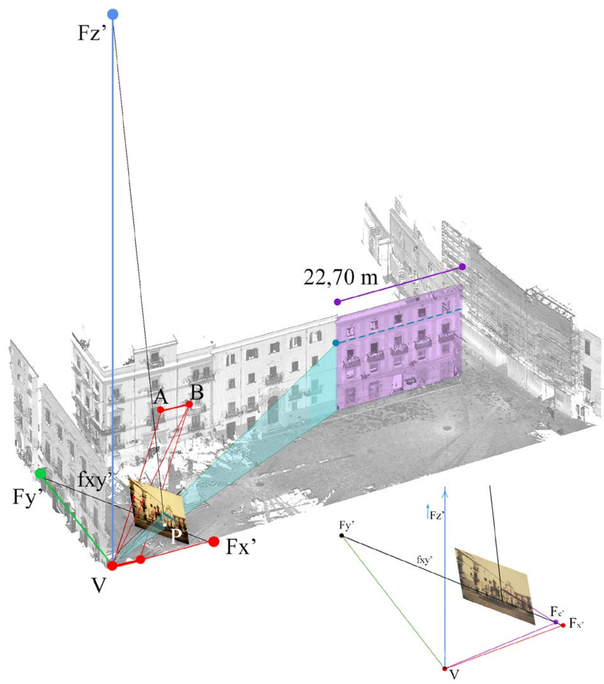

Figure 12. Orientation of the photo of Sevaistre.

It has been assumed that the façade of the church could be reasonably superimposed to the vertical plane of the façade of the university building. Points from the image were thus projected onto this plane and protrusions (cornices and the like) could be calculated with modeling and perspective tools (fig. 13).

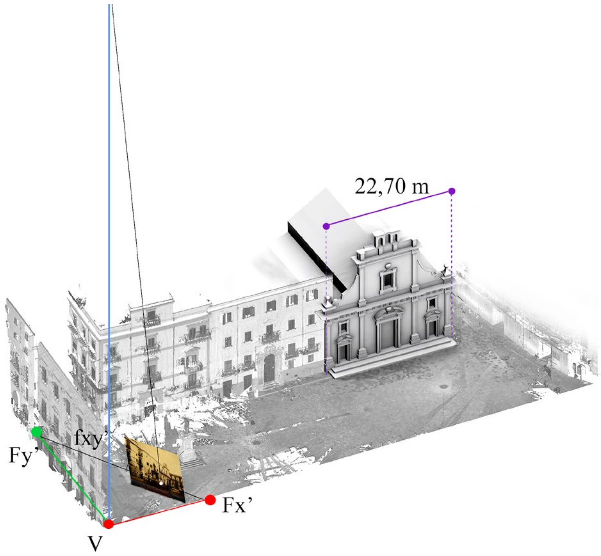

Figure 13. Reconstruction of the facade of the church.

Finally, the correspondence between the image of the façade and the view of the model from *V* has validated the reconstruction process.
The calculation of the intrinsic orientation of the images of the façade of the post office had to follow a different workflow, because the two images where the façade is portrayed, though retrieved in their full format, feature eccentric principal points *P* and vertical lines appear parallel and at straight angles with the vanishing line *fxy’*.
In this circumstance, *P* lies on *fxy’*. It has been assumed that the lens has been moved vertically and not horizontally; thus, the principal point has been fixed at the intersection between *fxy’* and the vertical line through the center of the image. Point *V* was finally detected, as stated before, at the intersection between the *principal line* through *P* and the sphere whose diameter corresponds to the segment *Fx’Fy’* (fig. 14).

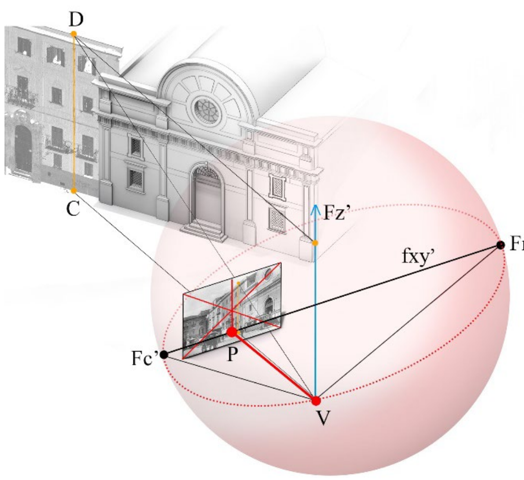

Figure 14. Reconstruction of the facade of the post office.

5. MIXED REALITY WITH MOTION TRACKING

Motion tracking tools use SfM algorithms to extract the path of a camera from a footage. The analysis of the frames leads to the automatic detection of trackers, i.e. points that are detected along a certain range of frames. As in SfM photogrammetry, the radiometric changes support the identification of trackers. The quality of the tracking is strongly conditioned by the resolution of the footage, by the features of the scene and by the stability of the camera.
The workflow of motion-tracking allows the users to create some markers/trackers and track them forward or backward in the sequence of frames.
Most motion tracking tools allow the identification of a reference horizontal or vertical plane and of a reference segment, for the orientation and scaling of the reconstructed camera’s path.
Motion tracking tools support the realization of videos where virtual objects are mixed to a real scene.
The prerequisite for the combination of the footage of the real scene and the animation of the virtual object is that the animation uses the same camera model and the same camera path of the footage.
The calculated path and camera model can be exported to a rendering tool; if the reconstruction model is properly referred to the coordinate system used for the orientation of the camera path, then the animation of the virtual object can be recorded using the calculated camera path.
The free software *Blender* supports all the steps needed for the realization of a mixed video: the calculation of the camera path, the recording of the animation of the virtual object and the video compositing. Blender has been successfully used in many researches (Cannella, 2021).
In this study, an experiment on motion tracking has been developed with the commercial software Syntheyes, because it allows to set the coordinates of trackers. The experiment addressed the possibility to use the point cloud recorded with the laser scanner both for the orientation of the SfM photogrammetric model processed with Metashape and for the camera path calculated with motion tracking algorithms (fig. 15).

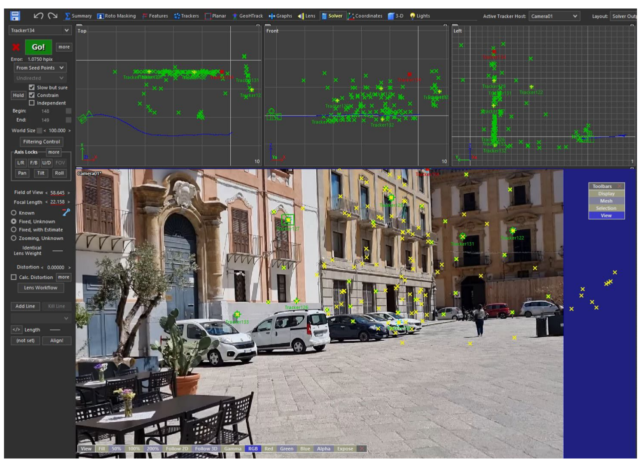

Figure 15. Orientation of the camera path in Syntheyes.

The footage shot in Piazza Bologni has been loaded in Syntheyes and some trackers corresponding to the markers used in Metashape have been detected and tracked. The coordinate of the trackers have been uploaded in Syntheyes and the trackers were converted into *Seed* points. Finally, the camera path has been solved.
The camera path has been exported in the Alembic file format and has been uploaded into Blender. The correspondence

between the camera path and the point cloud has been visually verified (fig. 16).
The correspondence allowed to record an animation of the reconstructed model and to mix it with the footage of the real scene.

Figure 16. The footage and the point cloud in Blender.

CONCLUSIONS

A couple of questions that emerged in this study demand further experiments: the accuracy comparison between Metashape and Syntheyes for the calculation of space resection, given the coordinates of points and the reliability of the results of automated SfM procedures, when photos have been taken with view cameras and the principal point is not at the center of the image.

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REFERENCES

Albertz, J., 2001. Albrecht Meydenbauer Pioneer of photogrammetric documentation of the Cultural Heritage: *Proceedings of the 18th International Symposium CIPA*, pp. 19-25.

Bajamonte, C., Lo Dico, D., Troisi, S., 2006: *Palermo 1860: stereoscopie di Eugéne Sevaistre*. Kalos editore, Palermo.

Bevilacqua, M.G., Caroti, G., Piemonte, A., Ulivieri, D., 2019: Rocnostruction of lost architectural volumes by integration of photogrammetry from archive imagery with 3-D models of the status quo. *ISPRS Archives*, Vol. XLII-2/W9, pp. 119-125.

Bitelli, G., Dellapasqua, M., Girelli, V.A., Sbaraglia, S., Tini, M.A., 2017: Historical photogrammetry and terrestrial laser scanning for the 3D virtual reconstruction of destroyed structures: a case study in Italy. *ISPRS Archives*, Vol. XLII-5/W1, pp. 113-119.

Cannella, M., 2021: Hulot's Selinunte: digital analysis and virtual reconstruction. *SCIRES*, Vol 11, Issue 2, pp. 113-124.

Condorelli, F., Rinaudo, F., 2018: Cultural heritage reconstruction from historical photographs and videos. *ISPRS Archives*, Vol. XLII-2, pp. 259-265.

Debevec, P., Taylor, C.J., Malik J., 1996: Modeling and Rendering Architecture from Photographs: A hybrid geometry and image-based approach. *SIGGRAPH '96*, pp. 11-20.

Deneux, H., 1930: *La Metrophotographie appliquée a l'Architecture*. Paul Catin Éditeur. Paris.

Docci, M., 1964: *Principi di fotogrammetria e restituzione prospettica di architetture*. Squarci. Roma.

El-Hakim, S., Beraldin, J.A., 2002: Detailed 3D reconstruction of Monuments Using Multiple Techniques. *ISPRS-CIPA Workshop*, Corfu, Greece, pp. 58-64.

Fallavolita, F., Migliari, R., Salvatore, M., 2013: Monge e il problema del vertice di piramide: una applicazione alla restituzione di quote e volumi da una fotografia del 1892. *DisegnareCon*, Vol. 6, n. 12, pp. 1-9.

Grammatikopoulos, L., Karras, G., Petsa, E., 2004. Camera calibration combining images with two vanishing points. *ISPRS Archives*, vol. XXXV

Laussedat, A., 1899: *La Métrophotographie*. Gauthier-Villars, Imprimer-Libraire. Parigi. 1899.

Leanti, A., 1761: *Lo stato presente della Sicilia (...). Tomo Primo*. Francesco Valenza impressore della Ss. Crociata, Palermo.

Lo Piccolo, F. (ed.), 2009: *Antonino Mongitore. Storia delle chiese di Palermo: i conventi*, vol. I. CRICD, Palermo.

Remondino, F., El-Hakim, S., 2006: Image based 3D modelling: a Review. *The Photogrammetric Record*, 21 (115), pp. 269-291.

Stefani, C., Busayarat, C., Renaudin, N., De Luca, L., Véron, P., Florenzano, M., 2011: An Image-based approach for the architectural modeling of past states. *ISPRS Archives*, Vol. XXXVIII-5/W16, pp. 398-404.

Wiedemann, A., Hemmleb, M., Albertz, J., 2000: Reconstruction of historical buildings based on images from the Meydenbauer archives. *ISPRS Archives*, Vol. XXXIII, Part B5, pp. 887-893.

Zawieska, D., Markievicz, J.S., Kopiasz, J., Tazbir, J., Tobiasz, A., 2017: 3D modelling of the Lusatian borough in Bispukin using archival data. ISPRS Archives, Vol. XLII-2/W3, pp. 665-669.

Van den Heuvel, F.A., 1998: 3D reconstruction from a single image using geometric constraints. *ISPRS Journal of Photogrammetry and Remote sensing*, n. 53, pp. 354-368.